REVIEW OF PROPERTIES OF COLLISION ENERGY ABSORBERS - EXPERIMENTAL AND NUMERICAL RESEARCHES

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Abstract *– One of the main assemblies in the front part of the rail vehicle structures are passive safety elements. Perennial researches in the field of passive safety produced several different types of collision energy absorbers. Subject of this paper is review of experimental characteristics of a few different types of energy absorbers that works on the principle of folding, shrinking, expanding, shrinking-folding and shrinking-splitting of the tube. Using these types of absorbers, the energy absorption occurs by elastic-plastic deformations of the tube and friction between the tube and the special tools. Experimental researches were realized via quasi-static tests in a laboratory conditions and via collision of two passenger wagons. These absorbers can be installed in a line with standard buffer or separately in a front part of the rail vehicles structure. Numerical simulations of different shapes of deformation were realized using finite elements method (FEM) while the numerical models were verified using experimental results. Main target of development was to design collision energy absorber of compact (acceptable) dimensions that has gradual increase of the force and requested absorption power. Using results of experimental investigations and numerical simulations, the main advantages and disadvantages of described types of collision energy absorbers were presented.*

Keywords – Passive safety, Collision Energy Absorbers, Numerical simulations, Experimental researches.

1. INTRODUCTION

The subject of this paper is a review of characteristics of several types of collision kinetic energy absorbers. These absorbers were developed and investigated in the previous twelve years within research projects financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia. Development of the energy absorber started with the elements using folding deformation process [1]. This type of energy absorber gives the peak of the force at the start of deformation process. These peaks can cause undesired deformations of the vehicle structure behind the absorber, before the full utilization of its material. Disadvantages of this type of absorber redirected further research on the expanding tube absorbers type [1]. Expanding of the seamless tube results in much better characteristics in comparison with folding absorber, but this type of absorber needs larger mounting space for absorption of requested amount of collision energy. In order to improve force vs. stroke characteristics as well as absorption power, quasi-static test of shrinking absorber was performed [2, 3]. In comparison with the previous two types of absorbers, shrinking process has most acceptable force vs. stroke characteristic and requires significantly less mounting space. Considering previous conclusions, further research was focused to additional reduce in dimensions of absorber and increasing of absorption power. This problem has been resolved using different combination of deformation processes. Characteristics of two types of combined energy absorbers were investigated: a) shrinking-folding and b) shrinking-splitting absorber,

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[4, 5]. Force vs. stroke characteristic of shrinking-splitting absorber has gradual increase of force during absorption process, while the shrinking-folding absorber characterizes jagged flow of the force in the phase of deformation when starts folding process. Both combined absorbers have compact dimensions and satisfactory absorption powers. Using expanding, shrinking and combined collision energy absorbers, energy absorption occurs by elastic-plastic deformation of the tube and friction between the tube and the special tools. Experimental investigations were realized using quasi-static tests and crash test via collision of two passenger coaches. Numerical simulations of only shrinking, shrinking-folding and shrinking-splitting deformation processes were done using finite elements method. Numerical models were verified using experimental results. Using experimental and numerical results, the main advantages and disadvantages of described types of collision energy absorber were presented.

2. EXPERIMENTAL INVESTIGATIONS

Experimental investigations were realized in the laboratory conditions using Servo-hydraulic machines LITOSTROJ 2500kN (GOSA Rolling Stock Company) and Zwick Roell HB250 (University of Belgrade Faculty of Mechanical Engineering), Fig. 1., as well as via collision of two passenger coaches (for only shrinking process).

Fig. 1. Test machines

Initial research of passive safety elements started with absorbers which work on the principle of folding the square tube under axial compressive loading.

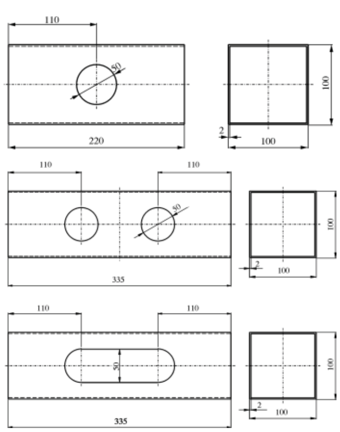

Fig. 2. Samples – folding absorber

Fig. 2 shows characteristic dimensions of three types of the tubes. Differences between the tubes presents shape of initial places where buckling starts. Initial places were designed as one circular hole, two circular holes and groove on the opposite walls of the tube. Tubes were made from steel grade S355J2G3 by bending and welding from 2mm thickness steel plates. Deformed samples are presented in Fig. 3. Experimental investigations of the folding absorber were realized in the laboratory conditions. This absorber type characterizes relatively low level of material utilization.

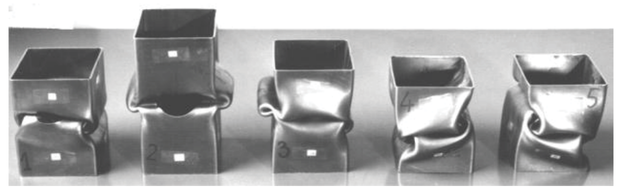

Fig. 3. Deformed samples – folding absorber

Disadvantages of folding absorber focused further research to other deformation process, expanding the seamless tube. Circular seamless tube was made from low carbon steel P235T1. Diameter of the tube was ∅88,9 mm and wall thickness 4 mm. This type of absorber works on the principle of expanding the tube using special cone tool, Fig. 4.

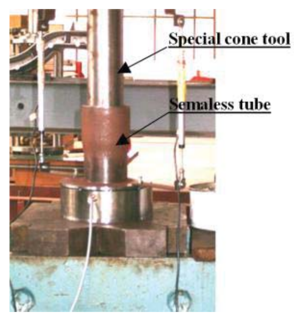

Fig. 4. Working principles – expanding absorber

This absorber has better force vs. stroke characteristics with gradual increase of the force in comparison with folding absorber. Disadvantage of expanding absorber is length of cone tool that requires a larger mounting space. This problem initiated new idea for energy absorption. It was the shrinking of the tube.

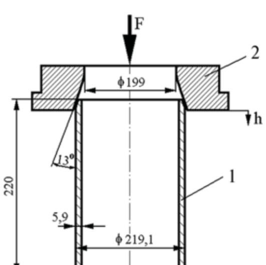

Fig. 5. Working principles – shrinking absorber

Shrinking absorber works on the principle of compressing the seamless tube (Item 1) through cone bush (Item 2), Fig. 5. Experimental investigations of this type of absorber were realized on a Hydraulic press and via collision of two passenger coaches (first Rail Vehicle Crash Test in Serbia and ex-Yugoslavia). Seamless tube was made from low carbon steel P235T1 with dimensions Ø219,1/6,7x205 mm, while the cone bush was made from quench and tempered carbon steel C45E with dimensions Ø219,1/Ø199/13°. Deformed shrinking absorber is shown in Fig. 6. During these research were analyzed strain rate dependence on deformation resistance, which is very important for further design and dimensioning of absorbers for different types of rail vehicles.

Fig. 6. Deformed sample – shrinking absorber

With the aim to increase absorption power and reduce dimensions as much as possible, further research was focused to combined energy absorber. This type of absorber using two different types of deformation processes to energy absorption, as follows: a) shrinking-folding and b) shrinking-splitting the seamless tube. Experimental investigations of these types of absorbers were realized on a scale samples, Fig. 7.

Fig. 7. Samples – combined absorbers

The following elements were used for this investigation: seamless tubes from low carbon steel with outer diameter of ø75 mm and length of 70 and 110 mm (material P235T1), cone bush with dimensions ø75/68x13° and die (splitting process) with dimensions ø61/r8 from quenched and tempered carbon steel grade C45E. Working with scaled samples in a large degree reduces development costs and gives very good image about behavior of material as well as about the shapes of deformations.

Thus, it is possible to precisely determine the amount of increasing the absorption power and desired shape of deformation, i.e. flow of the force during whole process of energy absorption. Fig. 8 shows deformed combined absorbers. As expected shrinking-splitting absorber gives more favorable force vs. stroke diagram in comparison with shrinking-folding absorber, which has jagged effect in the second phase of deformation, when the shrinking and folding deformation processes work together in parallel mode.

Fig. 8. Deformed combined absorbers

In addition, shrinking-splitting absorber requires less mounting space for the same amount of absorption power in comparison with shrinking-folding absorber.

3. NUMERICAL SIMULATIONS

Numerical simulations were performed using software package ANSYS (for only shrinking and shrinking-folding absorbers) and LS-Dyna (shrinking-splitting absorber). Using ANSYS software package and the finite elements method, the nonlinear numerical simulation on the plane axisymmetric model (shrinking and shrinking-folding) was performed using Perzyna model with rate dependent option, Fig. 9.

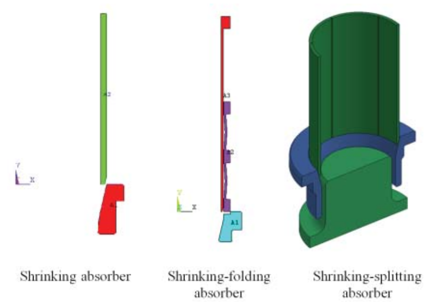

Fig. 9. Numerical models

Perzyna model requires defining key parameters which characterize rate dependent option, [6]. Using LS-Dyna software package and finite elements method, the nonlinear numerical simulation with fracture criteria on the 3D model (first from right in Fig. 9) was performed.

4. RESULTS

The following figures show characteristics force vs. stroke diagrams obtained by experimental investigations of described types of collision energy absorber. Fig. 10 shows F(h) diagram obtained by experimental investigations of folding absorber. This absorber produces undesired peak of the force at the start of folding (buckling) process. Force vs. stroke diagram recorded during quasi-static and dynamic tests of only shrinking process is shown in Fig. 11.

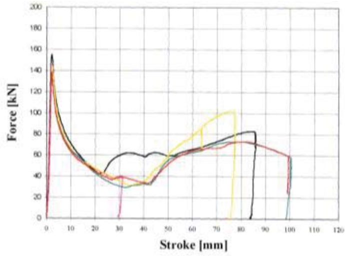

Fig. 10. F(h)diagram – folding absorber

This type of absorber characterizes gradual increase of the force until reached maximal value when remain at this level, with minor deviations, to the end of the quasi-static test (Fig. 11 left). Dynamic test gives higher values of the force, as expected, having in mind high sensitivity to strain rate.

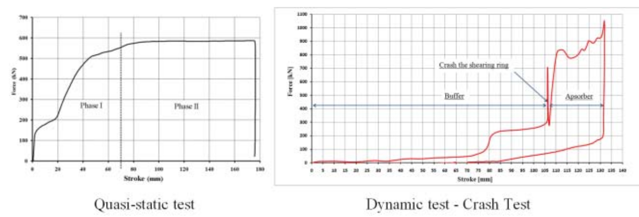

Fig. 11. F(h) diagram – shrinking absorber

Force vs. stroke diagrams, shown in Fig 12., obtained by experimental investigations of combined absorber. Left diagram presents characteristic curve F(h) with expected jagged effect in the second phase of deformation obtained by testing of shrinking-folding absorber, while the right diagram shows characteristic curve F(h) obtained by testing of shrinking-splitting absorber. It can be seen that the shrinking-splitting absorber has gradual increase of the force from the start to the end of deformation process, what is preferable in comparison with flow of the force using shrinking-folding absorber.

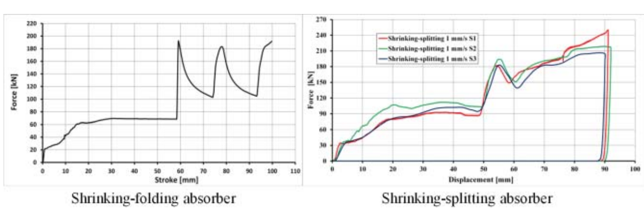

Fig. 12. F(h) diagram – combined absorbers

Fig. 13 shows shapes of deformations obtained by numerical simulations of only shrinking, shrinking-folding and shrinking-splitting absorber.

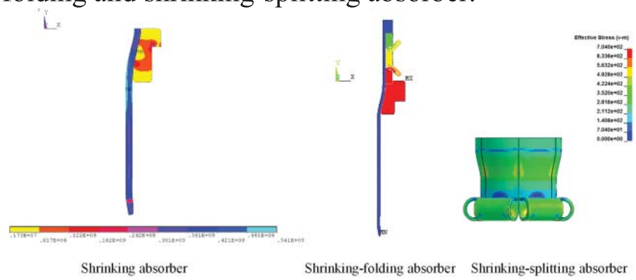

Fig. 13. Shapes of deformation – numerical simulations

Developed numerical models in ANSYS and LS-Dyna software packages are verified by experimental results and they serve for further research and modification of these types of absorbers whether for reducing dimensions or increasing absorption power.

5. CONCLUSION

Development of presented types of absorbers has significant role in future modernization of Serbian Railways, considering that majority of existing rolling stock, passenger coaches and freight cars, are not equipped with elements of passive safety. Results of experimental investigations show that combined shrinking-splitting absorber has the best F(h) characteristic, so it is most favorable for application on the rail vehicles. Developed numerical models reduce research costs and give great opportunity for modification of dimensions and absorption power without intermediate tests.

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